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VOLUME 82

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2. A 50-word summary should accompany the paper.

3. The manuscript (a ribbon copy and two copies) should be double-spaced on one side of 8½-in. by 11-in. paper. Papers that were originally prepared for oral presentation must be rewritten into the third person before being submitted.

4. The author's full name, Society membership grade, and footnote reference stating present employment should appear on the first page of the paper.

5. Mathematics are reproduced directly from the copy that is submitted. Because of this, it is necessary that capital letters be drawn, in black ink, 3/16-in. high (with all other symbols and characters in the proportions dictated by standard drafting practice) and that no line of mathematics be longer than 6½-in. Ribbon copies of typed equations may be used but they will be proportionately smaller in the printed version.

6. Tables should be typed (ribbon copies) on one side of 8½-in. by 11-in. paper within a 6½-in. by 10½-in. invisible frame. Small tables should be grouped within this frame. Specific reference and explanation should be made in the text for each table.

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Proceedings of the American Society of Civil Engineers

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Journal of the
SURVEYING AND MAPPING DIVISION
Proceedings of the American Society of Civil Engineers

EXPERIENCE OF THE BUREAU OF PUBLIC ROADS IN HIGHWAY SURVEYS[a]

William T. Pryor,[b] A.M. ASCE
(Proc. Paper 1117)

SYNOPSIS

New methods and practices in surveying are now ready to fulfill present needs throughout all States in the rapidly expanding highway construction program. Ground survey methods cannot be supplanted, but can, and should be, supplemented by photogrammetry and aerial surveys to attain better surveys and highways in less time with fewer engineers.

INTRODUCTION

The United States of America has become great through the urges, desires, and abilities of its people to change, progress, and cope with new problems of every kind, description, and magnitude. Today, our urges and desires are at an all-time high. Our problems are innumerable. For numerous reasons, many are questioning and wondering whether there are enough trained people to keep abreast of our ever-increasing problems.

In highway engineering there is no exception. Our highway problems are multiplying and becoming larger at an immeasurably rapid rate. Circumstances, economic forces, and convenience, comfort, and safety requirements are all demanding more and better highways. Current rates of highway construction—although much stepped-up beyond rates in past decades—are not fulfilling our needs. Combined with this realization are the facts that the current, yet insufficient, increase in highway construction reveals, in an alarming way, the shortage of experienced engineers, and points to the inadequacy of survey methods and practices in mode since our system of railroads was located and constructed before the advent of motor vehicles.

Note: Discussion open until May 1, 1957. Paper 1117 is part of the copyrighted Journal of the Surveying and Mapping Division of the American Society of Civil Engineers, Vol. 82, No. SU 3, December, 1956.

[a]Paper read at Convention of the ASCE, Knoxville, Tenn., June 4-8, 1956.
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Recently, Mr. A. C. Clark, Deputy Commissioner in charge of the Engineering Division of the Bureau of Public Roads, stated in his talk at a meeting of the American Association of State Highway Officials, that: "Current practices often require up to twenty-one months elapsed time, and in some instances even more time, from the date legislative authorized funds are apportioned to the actual commencement of construction. This delay is due in part to financing and right-of-way acquisition problems and in part to administrative determinations as to policies and priority of projects for programing. A substantial portion of the elapsed time, however, is consumed in performing the actual preliminary engineering operations."

Mr. Clark further stated that "The recently completed Highway Research Board survey of time-saving methods in highway engineering relating to location, and road and bridge design discloses increments of progress toward modernizing highway engineering practices. It also discloses that there is no concerted effort on a broad enough scale for a full 'package' modernization of highway engineering practices." It should be emphasized that it is in the preliminary engineering stages of our highway work that lie our greatest challenges for decreasing elapsed time and saving engineering manpower.

Questioners and wonderers are legion in the highway engineering profession, and they are justified in many ways in thinking that the still greater step-up soon to occur in highway construction will overwhelm the States and all highway engineering organizations. Few of them, however, feel that the equipment and materials manufacturers, the transporters of goods, or the construction contractors will fall short of meeting the demands of our new and larger construction programs. Their greatest concern now is in how can we accomplish the engineering work always necessary in preparation of plans before construction can be undertaken, and in performance of construction engineering, once the power shovels, tractors, trucks, and other equipment are at work.

What forces us to admit that less progress has been made in the improvement of engineering methods than in the improvement of materials, equipment, transportation, and methods of construction? Mr. Duane L. Cronk wrote in this month's issue of The Highway Magazine that ". . . .research people are. . . hard on the status quo. . .[they] change entire processes." The researchers he was referring to are the many who are learning new things about highway administration and finance; traffic; materials, equipment, and methods of highway construction and maintenance; and ways and means of improving the appearance, durability, and safety of our highways. On the other hand, he said nothing about the effect of research on surveys. Too little has been thought about, done about, and said about improving old and devising new ways and means of making the various surveys essential in each of the highway engineering stages—the surveys necessary to obtain the right kind and amount of information and data where and when needed by the staff of engineering specialists who cooperatively perform the preliminary engineering tasks required to prepare the plans needed by highway construction forces. This fact is now causing alarm in consequence of the known shortage of experienced engineers and the coming greater highway construction program. Even the reticent are much concerned. They realize that newer, faster, and fully satisfactory survey methods are necessary. Moreover, newer methods must make it possible for present engineering staffs to be responsible for larger expenditures and highway mileages. Otherwise, engineers will be forced to admit the inability of present staffs, which cannot be

much enlarged, to cope with the highway engineering tasks that lie ahead. Anticipating this situation, some have long been highly concerned. Fortunately, there have been a few—far too few to date—who have performed pioneering services in the adaptation into highway engineering of new survey methods from other professions, and in the development of new and the improvement of old methods. Others are now beginning to give the new and improved survey methods a try.

Such methods are aerial and photogrammetric in character, and have been pioneered for several decades by an "unlistened-to" few who had the foresight and courage to tread an unknown path full of obstacles and "doubting Thomases." Regretably, acceptance of the new and improved methods of these pioneers has been slow. The status quo has been held to tenaciously for many reasons.

These realizations and admissions by the reticent and the doubting are our greatest assurance that our urges and desires will raise us to the level where we will cope with these new problems in their increased magnitude. In doing this we will change our methods and improve our ways while working to attain our objectives. And in the highway field, our objectives are more and better highways adequate for our needs. Engineering is only a means to that end.

The Bureau of Public Roads has many responsibilities. Among its most important duties are the administration of Federal-aid in all States, the engineering and construction of highways to, in, and through our National Forests and Parks, and other Federal lands in 36 States, Alaska, and Puerto Rico; the performance of research; and the development of new and the improvement of old methods. In addition, the Bureau has cooperated, and now is cooperating, in the engineering and construction of highways in other countries. Admittedly, much of the surveying for all of this engineering work has been, and continues to be done, by ground survey methods. Full advantage has not been taken of opportunities to use aerial methods, but fortunately this practice is changing. A little more than a year ago, authority was received to negotiate for the services of qualified and reliable photogrammetric engineering firms and consultants. This authority, the enlarged construction program which will become larger, and the shortage of engineers are forces all working with the progressive, pioneering, few to bring about the needed changes in highway surveying practice.

Engineering and Surveying Stages

Preliminary engineering tasks are performed throughout a series of coordinated stages, and in each stage surveys of some kind are required. Usually, the surveys begin with the general and proceed to the specific. First, they are broad in scope and reconnaissance in character for determining all feasible route alternatives, wherein kind, type, condition, value, and relationship are most important. Second, they remain reconnaissance in character, become narrow in scope, and are for comparing the alternatives in sufficient detail to determine the route which has the most advantages in terms of service, comfort, convenience, safety, initial cost of right-of-way and construction, cost of motor vehicle operation, cost of maintenance, and cost of improvement to fulfill new requirements whenever traffic should increase beyond design capacity. The third is preliminary survey of the best route to

accurately measure dimensions and obtain sufficient information about topography, soils, drainage, land use, rights-of-way and the like for design of the highway location and preparation of plans. The fourth is the location survey staking of the highway, its right-of-way, and its structures on the ground in readiness for construction.

Throughout these stages consideration must be given to the multiple influences of traffic, in number, weight, speed, and access to the highway; right-of-way and land use bordering the highway-to-be; topography; soils, their kind and condition; drainage; appearance; convenience, comfort and safety. The complexity of these considerations has brought about replacement of the one-man highway locator by a large staff of specialists in the survey, design, and location of any major highway project.

Ground Surveys Versus Aerial Surveys

Mistakes in highway location can best be avoided by sufficient reconnaissance in the first two stages. And mistakes in reconnaissance cannot be corrected during preliminary survey in the third stage.

Reconnaissance on the ground is difficult and is often piecemeal in character, fitting well the adage—"he couldn't see the forest for the trees." On the ground, controls of location are at natural scale, and are usually so far apart that their significance and relationship are difficult both to determine and evaluate. In contrast, however, aerial photographs (refer to Figures 1 and 2) as a reconnaissance tool bring the topography, land use, soil and ground conditions, drainage, and all other controls of highway location into the office at a scale which will enable the engineering staff to see "both the forest and the trees," and the full significance and relationship of one control to another. Nothing need be missed, overlooked, or improperly evaluated. Every feasible route alternative can be determined and compared, in contrast to merely finding a way—never knowing whether it is the best or the worst—as when reconnaissance is accomplished on the ground in limited time by a one-man locator. In addition, each specialist on present engineering staffs can do his part while working with complete information when aerial photographs are at hand. But on the ground each individual usually obtains a different concept, and verifications or clarifications can be obtained only by repeated reconnaissance which is costly in terms of both time and money.

As an example, a reconnaissance survey was made a few years ago by aerial methods and route alternatives were determined between two terminal points 100 air miles apart. One year before this aerial survey was undertaken, a ground survey had been made for a 15-mile portion of the route where eight rivers had to be crossed and the topography was rugged. After the aerial survey had been completed, it was necessary to administratively decide whether the 15-mile ground survey should be held to or abandoned in favor of a similar length segment of the 120-mile through-route determined by aerial survey. Two years after the ground survey had been made and one year after the aerial survey had been completed, both routes were cleared on the ground, because they were in a densely vegetated, tropical region where regrowth is rapid and no clearing had ever been done previously on the aerial-surveys-determined route. Then, with profiles in hand, engineers walked over each route, made on-the-site estimates of highway and bridge construction costs, and compared these routes in alignment, grades,

Figure 1.--An aerial vertical photograph of a rural mountainous region where topography is irregular to rugged and ground cover is sparse to dense. This photograph is representative of the type which is useful in making an area reconnaissance survey to determine route alternatives while ascertaining soil and ground conditions, drainage, and other topographic controls of highway location.

Figure 2.—A small scale vertical photograph which is an example of the type usable in making an area reconnaissance survey to determine route alternatives, and ascertain and evaluate both the land use and topographic controls of highway location within suburban and contiguous rural regions.

curvature, and cross section. Results indicated better grades on the aerial survey route and an estimated savings in construction costs of $300,000 for grading and $400,000 for bridges—an average total saving of nearly $47,000 per mile. Another comparison can be made. Total cost for the 4,000 square-mile aerial survey was only $30,000 for all area and route photography, stereoscopic examination of the photographs, determination of over 240 miles of route alternatives, preparation of estimates of construction cost, comparison of routes, and recommendation of the best 120-mile route for preliminary survey, design, and construction. And the 15-mile partial route reconnaissance and preliminary survey made on the ground cost a like amount.

Once the reconnaissance is completed by aerial methods, engineers have an exact, detailed, photographic image record in stereoscopic correspondence of all routes determined and of the route chosen for preliminary survey (refer to Figure 3). Thus, with the photographs in hand to serve as the guide, the third stage preliminary survey can be made by an otherwise undirected party of a portion or all of the route at any time by either ground or aerial methods. But whenever the reconnaissance is made on the ground, the only guidance records available are the sketches, oral and written reports of the locator, and the flags, if any, which he set while going over the route he found. His immediate personal attention must be given to each mile of the preliminary survey to follow if it is to be made where he intended, and even he would find it difficult to begin anywhere and survey any portion of the route.

By ground survey methods only, it is also difficult, costly, and time consuming to make preliminary surveys of route bands sufficient in width to include all of the alignment, grade, and cross section possibilities on the chosen route, or to include the changes which usually become necessary but cannot be fully anticipated (refer to Figure 4). Conversely, however, a route band of topography two to twelve times as wide can be photographed (refer to Figure 5) and surveyed by aerial photogrammetric methods at less or equal cost.[1]

One of the disadvantages of aerial surveys in many regions is vegetation, associated to a degree with seasons. For example, wherever evergreen vegetation is tall and dense, only the reconnaissance surveys can be made by aerial methods, and the preliminary surveys have to be made on the ground under the trees. This is because a photogrammetric engineer cannot survey, cannot make measurements of the ground's configuration, if the ground cannot be seen on photographs taken from the air. And wherever deciduous trees grow, photography must be taken when the leaves are off the trees and the ground is not covered with snow.

Photogrammetric methods are sufficient for delineation and filling in required map details between seeable, identifiable points of known horizontal position and elevation. Such points are necessary, but they require the employment of ground survey methods to determine their horizontal position

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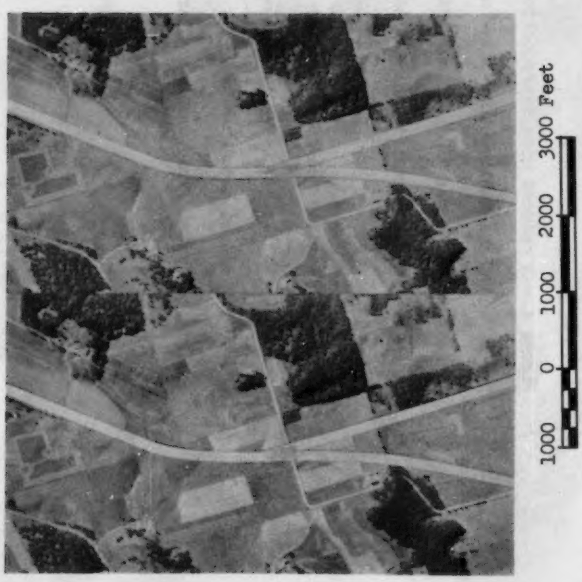
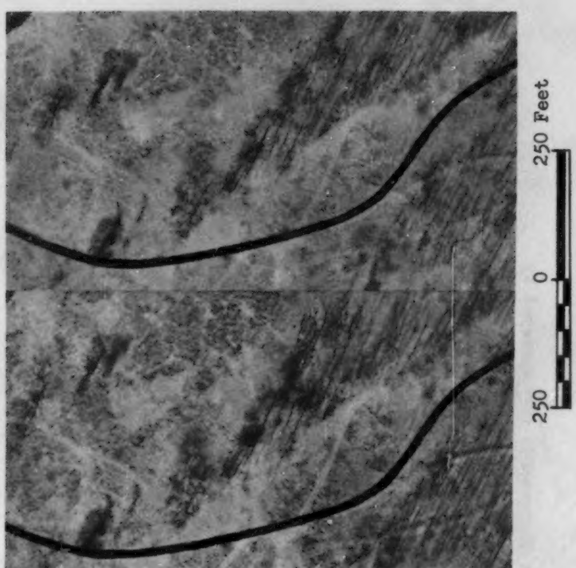
1. Refer to the table "Comparison of Preliminary Surveys for Highways, Aerial versus Ground," for detail on scales, widths of surveys, and costs. The higher costs of both aerial and ground surveys are incurred where the land use is intense, and the lower costs wherever the land use is small or nil and ground cover is light over rolling and smooth to nearly level topography.

Figure 3.—Delineation of routes in stereoscopic correspondence enhances illustrative value and is a valuable guide to field parties making a P-line survey of the route on the ground. To examine these stereograms stereoscopically, either one of two methods may be employed, a lens-type stereoscope or the unaided eyes. To examine a stereogram without a stereoscope, look at the left photograph with your left eye and the right one with your right eye. To make this easy, place a 10-inch card between your eyes from your face to the line between the pair of photographs of the stereogram. By this means, you are prevented from looking first at one photograph and then the other. With the card in place, look into the distance—like seeing through the paper on which the photographs are printed—until the three-dimensional picture is seen beyond the pages of the book. After a little practice, you can eliminate the card.



STEREOGRAM

Possible route alternatives placed on original photographs by use of white acetate tape.



STEREOGRAM

Possible route alternative drawn on original photographs by use of red china marking pencil. Photographic reproduction produces a black line.

Figure 4.—A reduced size reproduction of a topographic map surveyed by P-line and plane table methods several years ago. The working scale was 50 feet to one inch. The contour interval is five feet. This narrow width mapping was insufficient and the centerline (stationed at 500-foot intervals) ran off the mapped area. To complete the design, additional mapping was required, for which photogrammetric methods were employed. While the necessary additional mapping was being done, the previously mapped area was remapped. Thus, as both maps are on the same coordinate system, they can be compared in detail, accuracy, and reliability.

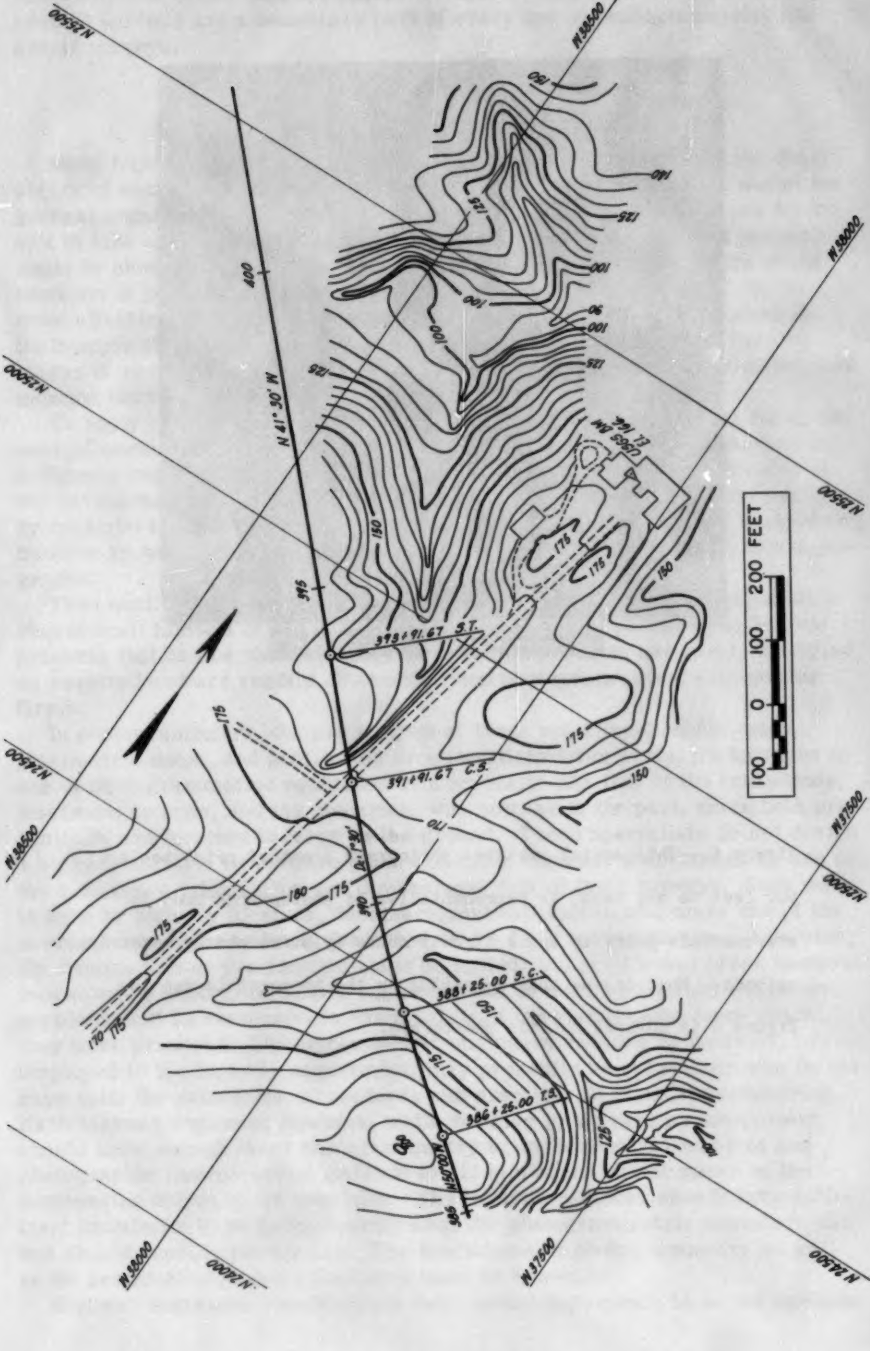

N 25500
N 25000
N 24500
N 24000
W 38500
W 38000
W 37500
N 41° 30' W
400
395
390
385
393+91.67 S.T.
391+91.67 C.S.
388+25.00 S.C.
386+25.00 T.S.
N 50°00' W
D=1°30'
USGS BM
EL 166
150
140
125
100
90
175
180
170
100 0 100 200 FEET

Figure 4

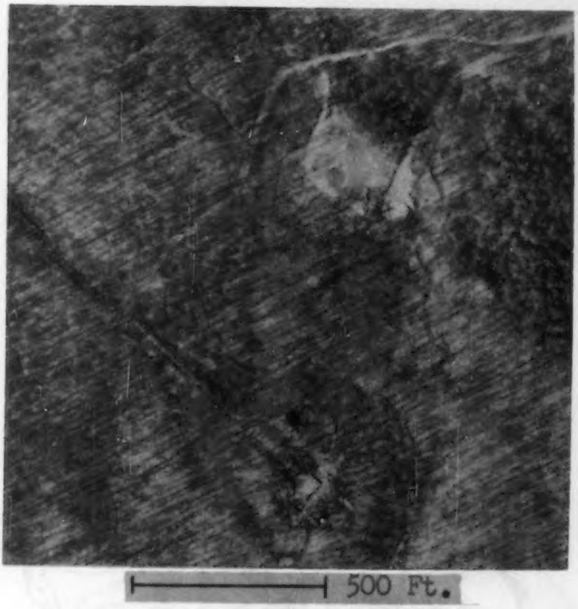


Figure 5.—This aerial vertical photograph (contact print scale of 500 feet to one inch) is representative of photographs used in stereoscopic pairs to map a highway route by stereophotogrammetric methods. Most of the area appearing on the topographic map in Figure 6 is covered by this photograph.

and elevation. Consequently, except for the reconnaissance stages, ground control surveys are a necessary part of every use of photogrammetry and aerial surveys.

Use of Aerial Surveys

Many highway departments have recently made inquiries about the desirability of establishing a photogrammetric and aerial surveys unit, and of the general organization and equipment that should be considered for use by the unit to take aerial photographs, make ground control surveys, and prepare maps by photogrammetric methods. This unit would be the supplier of the products of photogrammetry and aerial surveys, and not the user. To be most effective, the user of these products should be highway engineers in their application of photogrammetry to highway engineering from the two stages of reconnaissance through preliminary surveys, soils exploration, and location surveys to construction and maintenance.

To apply photogrammetry effectively in the highway engineering field, the user of aerial photographs first must be specialized as well as qualified as a highway engineer, and second must know how to apply photogrammetry in his particular work. This means that the scales most useful and the accuracy required from the photographs in each of the stages of highway engineering must be known, as well as the means available to obtain and to use the photographs.

Then each highway engineer in his present assignment and responsibility should avail himself of every opportunity to use aerial photographs and the products that can be obtained from them, which products are easily specified as required and are readily obtainable from photogrammetric engineering firms.

In photogrammetry, the preparation of large scale topographic maps, planimetric maps, and profile and cross sections from aerial photographs by use of photogrammetric equipment is a specialty like that of the transitmen, levelmen, rodmen, and the chainmen, who now, as in the past, make both preliminary and location surveys on the ground. These specialists do not design a highway location or prepare plans and make engineer's estimates by use of the qualitative information and dimensional data of their surveys. Such work is done by highway locators, designers, and estimators who make use of the survey information and data furnished by the field survey parties. Likewise, the topographic or planimetric maps compiled, and profile and cross sections measured by photogrammetric engineers can be used by highway engineers, supplemented by stereoscopic examination of the photographs from which they were prepared. Photogrammetric engineers engaged by contract, or employed in the highway department, may presently be specialists who do not know fully the principles, procedures and practices in highway engineering. Each highway engineer, however, while working in his special assignment should know enough about photogrammetry to apply photogrammetric and photographic interpretation methods to aid him in the performance of the engineering duties of his specialty. The highway engineer should have sufficient knowledge to properly specify what the photogrammetric engineers can and should provide for his use. The limitations of photogrammetry as well as its practical uses and advantages must be known.

Highway engineers should obtain their initial experience in aerial methods

Figure 6.--A reduced size portion of the topographic map compiled in 1956 by stereophotogrammetric methods of the same section of highway route partially mapped previously by P-line and plane table survey methods. The compilation scale was 100 feet to one inch. The contour interval is five feet. Ample mapping width in realistic detail was easily obtained. Dashed line contours, however, are in densely wooded areas where the same degree of detail and accuracy could not be obtained as where the ground is easily seen. The centerline of the initially designed location is the heavy line stationed at 500-foot intervals. Compare the character and completeness of contours and other details on this map with the map surveyed by plane table, Figure 4. Evidently, sketching by interpolation on the plane table between points of finite measurement only furnishes outlines and fails to provide details.


N 41°30' W
393+91.67 S.T.
391+91.67 C.S.
388+25.00 S.C.
386+25.00 T.S.
N 50°00' W
100 0 100 200 FEET

Figure 6

by use of aerial photographs for reconnaissance purposes only. Such photographs may be obtained from available sources of areas where use of the land has not changed much since the photographs were taken, or they should be photographs newly taken of areas where vital changes have occurred and up-to-date information on land use is needed. Topography changes little throughout the years, but land use changes rapidly near metropolitan areas.

The reconnaissance of an area to determine feasible highway routes can largely be accomplished by the use of small scale aerial photographs and the less complex photogrammetric instruments, such as mirror and lens type stereoscopes, engineer's scales, parallax bars, stereocomparagraphs, contour finders, the elevation wedge, and stereo-slope comparators. In addition, aerial photographs can be used for illustrative purposes to show: (1) the engineering problems caused by conditions existing before the highway is located; (2) perspective views of what the highway will look like when built, as designed on the best route; (3) a picture of the highway when constructed (refer to Figures 7 and 8); and (4) appearance of the highway after use by traffic, including changed conditions.

For reconnaissance, highway engineers with location and design experience should use the photographs stereoscopically, and the best available maps. For the illustrative uses an artist familiar with highway engineering, who is fully skilled in the art of perspective delineation on photographs, is essential. In addition, it is best to have the service of a photographic laboratory, where, from aerial negatives can be prepared contact prints, photographic enlargements and photographic mosaics of both the uncontrolled and the controlled types (refer to Figure 9). This means that a contact printer, a precise photographic enlarger, photographic copy camera, and radial line plot equipment should be in the laboratory.

Photogrammetric Engineering Services

Once a highway department has made an initial start in the application of photogrammetry and use of elementary photogrammetric equipment in the reconnaissance stages, it can judge better the extent to which it should staff and equip itself to use aerial photographs and precise photogrammetric methods in the preparation of large scale maps for the preliminary survey. In the meantime, however, while using photogrammetric methods for reconnaissance, it may make its preliminary surveys on the ground or contract with reliable photogrammetric engineering firms, which are equipped and staffed to perform such services, for the preliminary survey photography and large scale route mapping. There are many advantages in engaging the services of these firms, especially for the aerial photography and mapping. Specifications can be written which make it practicable to obtain aerial photographs and maps to the scales needed, and within the limits of accuracy required. Such specifications, when complied with, would assure results of uniform quality at a reasonable and an initially known cost.

For economic utilization of precise photogrammetric methods for mapping, there is a relationship between map scale and contour interval which should be observed. Expressed numerically, the map scale in feet to one inch should be 40 times the contour interval in feet. Some representative map scales in feet to one inch and the corresponding contour interval in feet are: 200 feet and 5 feet; 80 feet and 2 feet; and 40 feet and 1 foot. Wherever maps are

Figure 7.—An especially large scale aerial vertical photograph (its scale is about 340 feet to one inch) showing highway construction in progress, including grade separation structures and temporary detour. Such photographs can be used for illustrative, interpretive, and record purposes as well as for large scale mapping and measurement of profiles and cross sections of the completed highway to compute the final grading quantities.

Figure 8.—An aerial high-oblique photograph in the lower part of which can be seen the highway construction shown on the preceding vertical photography, Figure 7. This photograph is called a high oblique because the horizon line appears in the upper part of it. Depending upon the sequential time in which they are taken, such obliques are useful before-, during-, and after-construction records of highways, and their problems and proposed solutions. They are also excellent for illustrative purposes.

required at scales of 100 feet or 50 feet to one inch, these can be obtained by photographic reduction in map size and scale from 80 to 100, and from 40 to 50 feet to one inch, while retaining the contour interval of 2 feet and 1 foot respectively.

There are reasons for having a photogrammetric unit to prepare topographic maps from aerial photographs the same as there are reasons for having an engineering organization to make surveys and to supervise construction instead of periodically employing consulting engineers. The principles and ideas with regard to consultants in the survey and construction field would apply to the services of photogrammetric engineering firms. When specifications are not complied with, consultants can be required to do the work over at their expense until compliance is attained. But any work incorrectly done by the payroll employees will have to be done over at the employer's expense.

Testing the adequacy and the accuracy of position in map details, of contour elevations, and of profile and cross-section measurements constitutes an arduous and unliked task. Coupled with these disadvantages are the delays which occur whenever maps or measurements photogrammetrically made fail to comply with specified accuracies.

A near-ideal situation will exist when all maps and measurements made photogrammetrically can be tested by the same methods rather than having to resort to traverse running, profile measuring, and position testing by ground survey methods. And the ideal will be attained when all photogrammetric work is so accurate and reliable that all tests can be eliminated. Present methods of photogrammetrically testing maps in conjunction with a few measured spot elevations and positions are a step toward attaining the near ideal.

Among the principal advantages of employing the services of photogrammetric engineering firms by negotiated contract are that payroll employees are relieved of the arduous, time-consuming task of making surveys. Thus, they will have more time for the performance of their other professional engineering duties of designing highway locations, preparing plans, and procuring rights-of-way by use of the aerial photographs, photographic mosaics, maps, profile, and cross sections provided by such firms.

Another advantage is the fact that highway stakes need not be set until staking for construction is necessary. In this way right-of-way acquisition problems are decreased through the projection of trial locations on maps without alarming the public and property owners by numerous preliminary survey lines on the ground. And still another advantage is the continuity that can be obtained by the completion of surveys, designs, and plans from terminal point to terminal point well in advance for right-of-way acquisition before land values increase and construction funds are available or allocated.

With the recent development of electronic methods of computing end areas, earthwork volumes, mass diagram values, survey traverses, and the like, photogrammetric methods properly employed are their natural, efficient companion. The designs can be completed without plotting cross sections from ground survey measurements or from photogrammetrically prepared maps. Instead, the profile and cross sections can be measured and their dimensions recorded photogrammetrically for making the electronic computations. Likewise, the highway alignment can be computed and fully coordinated to ground survey position in the system of State plane coordinates through the station markers set while the ground control surveys were made for the

Figure 9.—Semi-controlled photographic mosaic of the central part of Denver. On this mosaic is shown a possible location for the Valley Highway Project, a section of the limited access highway to be constructed into and through Denver. Parts of this highway are now completed. Such a mosaic is useful in conjunction with available maps and the stereoscopic examination of aerial vertical photographs to determine route alternatives for comparison and selection of a route for preliminary survey to design the highway and prepare construction plans. It is also an excellent medium for illustrating the route alternatives or the recommended route. Original scale was approximately 800 feet to one inch.


VALLEY HIGHWAY PROJECT
DENVER COLORADO
WEST FIFTY SECOND STREET
TO
TENTH AND ZUNI STREET
CITY OF DENVER
COLORADO STATE HIGHWAY DEPARTMENT
U.S. BUREAU PUBLIC ROADS
1000 0 1000 2000 3000 4000 FEET

mapping. And for any projects more than 2,000 feet above mean sea level, the coordinates of such markers should be adjusted to apply at the average elevation of the area of survey rather than to apply at the sea level datum. The obvious reason for this adjustment is to make measurements of distances on the map correspond correctly with horizontal measurements on the ground; thus eliminating the need for correction of each map distance.

CONCLUSIONS

While surveying practice has been slow to change, highway engineers cannot escape the demands our present situation is making for improvements. Acknowledging this fact is our first step forward. Our next step is to take advantage of methods new to many but which have proven themselves when fairly tried. And finally, the more there are who do this, the greater our advances will be through change and improvement, and the better qualified and capable we will become to cope with the multiplicity of highway problems now confronting our country.

Table 1.
COMPARISON OF PRELIMINARY SURVEYS FOR HIGHWAYS
AERIAL VERSUS GROUND

MAP SCALE	CONTOUR INTERVAL	AERIAL SURVEYS			GROUND SURVEYS			Number of Times Aerial Survey is wider than Ground Survey
			COST-DOLLARS			COST-DOLLARS		
Repre-sentative Fraction and Feet to 1-inch	(Feet)	Average Width of Survey (Miles & Feet)	Per Square Mile and Acre of Mapping	Per Route Mile of Highway	Average 1/ Width of Survey (Miles & Feet)	Per Square Mile and Acre of Mapping	Per Route Mile of Highway	
1:480 40	1	1/5--1/4 (1,050--1,320)	3,000--16,000 (5--25)	600--4,000	1/30--1/16 (180--330)	12,000--48,000 (19--75)	400--3,000	6--4
1:600 50	2	1/4--1/2 (1,320--2,640)	2,500--12,000 (4--19)	600--6,000	1/24--1/8 (220--660)	10,000--32,000 (15--50)	400--4,000	6--4
1:1,200 100	2	1/2--1/4 (2,640--1,320)	1,400--10,000 (2.2--16)	700--2,500	1/12--1/8 (440--660	7,700--24,000 (12--37)	640--3,000	6--2
1:1,200 100	5	1/2--1/4 (2,640--1,320)	1,000--6,400 (1.6--10)	500--1,600	1/12--1/8 (440--660)	4,800--13,600 (7--21)	400--1,700	6--2
1:2,400 200	5	1 (5,280)	400--1,000 (0.6--1.6)	400--1,000	1/6--1/8 (880--660)	2,700--9,600 (4--15)	450--1,200	6--8
1:2,400 200	10	1--2 (5,280--10,560)	250--600 (0.4--0.9)	250--1,200	1/6--1/8 (880--660)	2,100--8,000 (3.3--12)	350--1,000	6--16
1:4,800 400	10	2 (10,560)	150--400 (0.2--0.6)	300-800	1/5--1/6 (1,050--880)	1,500--4,800 (2.3--7)	300-800	10--12
1:4,800 400	20	2 (10,560)	100--300 (0.2--0.5)	200--600	1/5--1/6 (1,050--880)	1,000--4,200 (1.6--6)	200-700	10--12

1/ These are the widths surveyed by ground methods at about the same cost per route mile of highway as the wider widths are surveyed by aerial methods.

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THE USE OF PHOTOGRAMMETRY TO CIVIL ENGINEERS[a]

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SYNOPSIS

A discussion of the many uses where photogrammetry will aid the Civil Engineer in designing highways, water and sewerage systems, power transmission lines, airports, and city development. Saving in cost and time are illustrated by specific projects when photogrammeteric methods are employed in place of conventional ground surveys.

Photogrammetry is the science or art of obtaining reliable measurements by means of photography.

It is interesting to note that the word "photogrammetry" came into general usage in the United States at about 1934, the time the American Society of Photogrammetry was founded, although the term already had been widely used in Europe for several years. It is derived from three Greek words, one meaning light, a second meaning a drawing or graph, and the third meaning to measure. The root words, therefore, originally signified measuring graphically by means of light.

Photogrammetry is frequently divided into specialities or categories, according to the type of photographs used, or the manner of their use. For instance, the type of photogrammetry used when the photographs are taken from points on the ground surface is called ground photogrammetry or terrestrial photogrammetry. Photographs taken on the ground with the optical axis of the camera horizontal are called horizontal photographs. Aerial Photogrammetry connotes the use of photographs which have been taken from any airborne vehicle, and these may be either vertical aerial photographs, or oblique aerial photographs. Stereo-photogrammetry means that overlapping pairs of

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photographs are observed and measured, or interpreted, in a stereoscopic viewing device, which gives a three-dimensional view and creates the illusion that the observer is viewing a relief model of the terrain.

Vertical aerial photographs are best known and most used at the present time, although much of the early development of the basic theory of photogrammetry was evolved from horizontal and oblique photographs. Vertical photographs are those taken with the optical axis of the lens pointing vertically at the time of the exposure.

In precise photogrammetric instruments, means are provided for determining conveniently the amount of tilt in each photograph so that rectification to the equivalent of the true vertical can be accomplished by simple adjusting devices. Therefore, even though such instruments are used principally for accurate map compilation, the lack of true verticality in the pictures should not affect the accuracy of the final results.

During the past twenty years there have been remarkable development in aerial cameras, photographic material, and stereoscopic plotting equipment.

As of today, photogrammetry is established as a basic procedure in all types of mapping, from the small-scale and generalized exploratory charts to the exceedingly detailed contour maps of cities and construction sites. In fact, there is little of any kind of original mapping being done anywhere in the world today that does not utilize photogrammetry in one way or another. Its most intensive and advantageous use in mapping is probably in connection with various mapping operations by the United States and other governments. Today, photogrammetry is a recognized and respected profession in a majority of countries of the world, and, it should be noted, is being increasingly used to great advantage in numerous activities other than mapping, including exploration, military reconnaissance, geology, forestry, agriculture, construction, city planning, and medicine. However, I will confine this discussion to the use of photogrammetry in connection with civil engineering projects.

Certain standards of map accuracy have been established for maps published by agencies of the Federal Government. These standards of accuracy have been prepared by representatives of the various departments and approved by the Chief Examiner, Surveying and Mapping, Bureau of the Budget. These same standards are generally used for all types of photogrammetric mapping as applied to highway and other types of engineering projects. Horizontal accuracy—for maps published at scales larger than 1:20,000, not more than 10 percent of the points tested shall be in error by more than 1/30 inch, measured at the publication scale; for maps published at scales of 1:20,000 or smaller, this tolerance is 1/50 inch. Vertical accuracy, as applied to contour maps at all publication scales, shall be such that not more than 10 percent of the elevations tested shall be in error more than one-half the contour interval and no point shall be in error by more than the contour interval. In checking elevations taken from the map, the apparent vertical error may be decreased by assuming a horizontal displacement within the permissible horizontal error for a map of that scale. Published maps meeting these accuracy requirements shall note this fact in their legends as follows: "This map complies with the National Standards of Map Accuracy Requirements."

To facilitate ready interchange and use of basic information for map construction among all Federal map making agencies, manuscript maps and published maps, wherever economically feasible and consistent with the uses

to which the map is to be put, shall conform to latitude and longitude boundaries, being 15-minutes of latitude and longitude, or 7-1/2-minutes, or 3-3/4-minutes in size. In our work it has also been the practice to tie all maps into the State Coordinate Systems as adopted in 1936 and to show this grid on the face of the maps. This permits the use of existing control of the U.S.G.S. and Coast and Geodetic Survey and results in an absolute tie between various projects. These maps become very useful to the surveyor who desires data for reducing a land survey to a State grid so that its results can be placed on a lasting basis and coordinated with surveys in other areas. In accomplishing this, only plane surveying methods and formulas are employed.

To illustrate the title of this paper I have attempted to break down and illustrate by specific projects the use that photogrammetry can be to the Civil Engineer.

The first of these is the Constitution Boulevard Highway Project at Aliquippa, Pennsylvania, which has been widely publicized, because it is the first contract under the Pennsylvania Department of Highways where photogrammetric methods have been used in determining quantities of excavated material. The old existing two-lane highway has been carrying approximately 11,200 vehicles daily to the Jones and Laughlin Plant and between the Pittsburgh and Beaver Valley areas. Slides from the steep hillsides just adjacent to the highway have caused many accidents and in one single case 22 deaths. The hillsides consist of hard shale, sandstone and limestone. The present roadway is crowded between the main line tracks of the New York Central Railroad and the steep hillside rising approximately four hundred feet above the level of the roadway. Along most of the area the lower slopes have weathered away leaving vertical rock formations exposed. During the rainy season and in the spring months when alternate freezing and thawing occur, these rock formations slide frequently.

During the Spring of 1953 the Pennsylvania Highway Department signed a contract with Michael Baker, Jr., Inc. for the preparation of a preliminary report outlining the costs and proposed location for a new four-lane divided highway. This two and one-half mile stretch of highway would start at Aliquippa and extend to the Borough of South Heights, connecting to an existing four-lane road. Studies were made to determine the feasibility of a complete relocation using a route over the high, less densely built-up area. However, in order to adequately fulfill traffic needs, it was found necessary to construct the new highway in approximately the same location as the old highway, allowing for interchanges to serve the traffic originating at the Jones and Laughlin Steel Corporation.

On May 10, 1953, aerial photographs were taken of the area using a Fairchild Cartographic Camera with a 6" calibrated lens, flying at altitudes of 2,400 feet and 4,800 feet above the average ground elevation. Ground control was established along the railroad tracks bordering the highway and on top of the 400 foot buff. Control points were established with such accuracy and density to satisfy the plotting of two-foot contours by photogrammetric methods. A working model, the area covered by the overlap of two adjacent pictures in a flight, generally contained three to four horizontal and vertical control points. The length of traverse and level line required was approximately twice the length of roadway to be studied. Because the traverse and level line were run on top of the hill, it was relatively easy to establish field control for the project. These same control lines served as base lines during the construction phase of the project to help establish slope stakes and to tie

in the stakeout for construction with the original contour plans. Contour maps were prepared using the low altitude photography to plot two-foot contours of the valley floor and the higher altitude photography to plot five- and ten-foot contours of the steep hillsides. A Kelsh Plotter was used for the preparation of these maps, but because the photography was not accomplished until late Spring (May, 1953), a few areas were covered with a tight screen of dense foliage. This made accurate plotting of contours difficult. With the aid of field inspections and spot survey cross sections at critical points, the maps prepared were more than adequate for the preliminary study. It was intended at this time to use these maps only for the preliminary study and cost estimates. An aerial mosaic was also prepared for the preliminary report. Tentative locations were shown on copies of this mosaic and helped greatly in studying property damage and other factors to arrive at a final location.

During the Winter of 1953-54 many slides occurred causing additional accidents and completely blocking the highway to vehicular traffic. Detours of several miles were required to take the place of the existing road. Because of these additional slides and accidents, the Highway Department in the Summer of 1954 decided to start excavation on the project immediately and requested the engineering consultants to produce final design drawings within sixty days along with construction plans for the grading contract. These plans were to be based on the topographic information contained on the previously completed photogrammetric maps. The fast schedule put an unexpectedly heavy premium on the accuracy of the preliminary work.

Consideration was given to the horizontal slice method of calculating quantities. By this method the volume of earth between contours would be figured based on the excavated area with each contour. However, it was decided by the State Highway engineers that cross section sheets would be required for the contractors' use in the field and quantities were, therefore, based on cross sections prepared from the contour maps. The volume of excavation as computed by this method amounted to nearly 2,800,000 cubic yards. This quantity was used in the bidding proposal, along with a statement that the cross sections had been developed by photogrammetric methods. The contract further specified that the successful bidder must accept photogrammetric methods as a basis for computing final pay quantities. Because the original photography was taken when the foliage was out, the consulting engineers reflew the strip at their own expense during the Winter of 1954. This new photography was used to check the original contour maps. In addition, cross sections were taken by ground survey methods at certain locations. These rechecks of the topography have confirmed the accuracy of the original cross sections and quantity estimates within 5%. This degree of accuracy is as good as could be obtained by field survey methods in country as rough as this, where ground parties working the steep slopes and using ropes over the cliffs do well to complete just a few cross sections a day.

Although aerial photographs, mosaics, and contour maps have been used by the Pennsylvania State Highway Department for several years, this is the first project in which the contract states that quantities will be based on photogrammetric surveys. Although this is an unusually difficult area to be used as a test, it has proven practical and acceptable to both the Highway Department engineers and the contractor. It is safe to say that the start of construction was advanced at least four to six months by photogrammetric methods and survey costs reduced by 80% to 90%.

It is expected that excavation on this project will be completed during the

fall of this year. New aerial photography of the area will be obtained after the grading is completed, using the original control points established. Then final topographic maps will be prepared by photogrammetric methods. We feel that this particular contract and the methods employed are a definite step forward for the acceptance and general use of photogrammetry in highway design and construction work.

Of interest to those who will be engaged in the planning and design of the highways under the new $51 billion, 13-year national roadbuilding program is the provision in the House-passed bill: "In carrying out the provisions of this title the Secretary of Commerce shall, to the fullest extent practicable, authorize the use of photogrammetric methods in mapping, and the utilization of commercial enterprise for such services." The Public Works Committee report commented that this language was inserted "because of the almost spectacular results in savings of time, manpower, and costs through use of the techniques developed from the interpretation of aerial photographs and their application to mapping. . . ." The Committee said it desired to encourage the Bureau of Public Roads and the States to continue and extend "their already well-advanced usage of this method" to the enlarged program.

Methods are now being developed to utilize electronic computers in conjunction with photogrammetric plotting equipment to determine highway location, and construction quantities. These methods undoubtedly will be in common use within the next two-years because of the greatly expanded highway program.

Illustration two is the use of photogrammetry as applied to sanitary engineering projects. Aerial photographs were used in the development of a new water distribution system for Brighton Township, Pennsylvania to determine most of the data needed for design: the number of homes to be served, the distance between them, the vacant land, the general types of usage whether residential, commercial, industrial, or agricultural and the service areas. A trip over the ground supplied missing data without recourse to detailed field surveys. This original system completed in 1952 consisted of thirteen miles of pipeline in an area which could be designated as rural-residential. Final construction quantities did not vary more than 1% from the original estimates made from the photogrammetric survey. Since that time, several other water distribution systems have been designed using the same method.

The municipal division of the company delighted with the success of its initial use of aerial photography next used photogrammetric maps for the planning of a sewage collection system and treatment plant. Here, accurate contour maps were needed because of the great importance of gradient. The project covered a small township with a population of less than 2000. The same advantages as mentioned in the water distribution system were noted in the sewage collection system: the number of houses, the type of usage, the vacant land, and the distances were easily determined. In addition, however, a supplementary advantage was gained. In most preliminary engineering surveys several alternate solutions are possible. Use of ground surveys alone practically prohibits investigation into all of the possible solutions, and therefore frequently the best solution is not found because of the time and expense involved. With photogrammetry, all avenues are available for study. There is no limit to the information which is available and the most economical, most practical method for layout of pipelines, pumping stations, and force mains can be determined.

As we know, photogrammetric surveys have been used for many years for

long pipelines and similar facilities. Recently we used photogrammetry for the selection of a path for microwave transmission which consists of a string of towers approximately thirty miles apart. Since the microwave beam is transmitted on a line-of-sight basis, the height of the towers and the terrain between the towers is a deciding factor. By photogrammetry, we were able to evaluate six different paths and select the most feasible path for microwave transmission.

We have also recently completed the route selection for a high voltage power transmission line. Again the height of the towers and the height of the catenary of the wires over intervening terrain is very important, and photogrammetry was used to determine tower heights for steel fabrication.

Another very interesting use of photogrammetry is the study of approach and clearance zones for commercial and defense airports and for guided missel launching sites. Examples of these are the Greater Pittsburgh Airport, the Harrisburg State Airport, and the NIKE sites around Pittsburgh and Cleveland. Where irregular topography exists adjacent to an airport, there must be complete knowledge of the relationship between the theoretical path of flight and the ground beneath it. Complete planimetric and topographic maps of the approach zones were obtained and upon these were superimposed the contours of the aerial glide path, providing a three dimensional analysis. This made possible an accurate study of the obstructions in the area and permitted planning for the elimination of hazards or for the erection of warning lights. These same maps were used to determine the areas required for purchase or easement.

The next use, where photogrammetry can be applied to engineering work is best illustrated by comparing this modern mapping method with the "Technical Procedure for City Surveys" as published by the American Society of Civil Engineers in 1934. This manual states that detailed mapping on 200' scale requires one instrument station for every one to two acres and five to twenty stadia readings per acre to control the plane-table survey. On this basis a four man survey party would probably cover eight to twelve acres per day or a maximum of three acres per man day. Using a stereo-plotter and using only the basic control set up for the topographic survey, one man could complete approximately two hundred acres per day in accordance with the same standards of accuracy as required by the field methods. These topographic maps should be prepared as the second step in the overall "City Survey" procedure immediately after establishing the basic control. They will aid greatly in establishing street and alley lines in addition to the lines between properties. Take for example a city block where the properties have been sold by deed dimensions or by old recorded plats which do not accurately depict the conditions on the ground. Many of these deed descriptions will not tie together and may show variations in the width or length of the block by ten to thirty feet. Actually, a large section of a city or town should be studied at one time to determine the correct location of street and property lines.

This study can best be made using a topographic map prepared by photogrammetric methods on which is shown all existing ground conditions including identifiable lot and street lines. By studying a large area at one time the alignment of streets and alleys, and the location for any excess or deficit within a block can best be determined. This is because all ground features can be scaled within the accuracy of the map and any major errors in deed descriptions can be determined. After the street locations have been established on paper, it would be necessary to go into the field and place permanent

monuments tieing in with the property boundaries. It can be seen that the use of photogrammetry makes possible preparation of a complete city map showing all existing features at a much cheaper cost than could be done with field survey methods. It also reduces the amount of 2nd and 3rd order traverse required and speeds up the whole process of preparing city maps. Example of the maps prepared by this method are the City of Niles, Ohio, and the Borough of Lewistown, Pennsylvania.

Another phase of city and county mapping is being performed in the State of Pennsylvania as required of all 5th to 8th Class Pennsylvania Counties by the 1951 Session of the State Legislature. This Legislature affecting 59 of the 67 Counties of the State requires tax maps of the entire County drawn to scale and indicating all property and lot lines. Since these maps are designed to be an inventory of the properties in the County, aerial photography is really the only answer for the basic information. After the property lines are identified on enlargements of the aerial photography, Kelsh plotters and Multiplex equipment are used in the compilation of the tax maps. Government control, published by the U.S.G.S. and the Coast and Geodetic Survey, is used for plotting operations, which allows all the tax maps to be tied into the State Coordinate System. The items to be furnished to the counties include a complete set of linen tracings showing dimensions or acreages of all parcels and a set of photographic enlargements on which are identified all property lines. A card index system is established which is cross-indexed to the appraisal cards and indicates the location of each parcel on the tax map and also on the enlarged photograph. In the preparation of these maps, aerial photography is an absolute necessity to insure that property lines are established in their true location and that all properties in the County are accounted for.

Another phase of photogrammetric mapping, which has grown considerably in the last few years, is performed for various utility and transportation companies. An example of this is a project recently completed for the Pennsylvania Railroad Company consisting of 5-foot contour maps at a scale of 1" = 100', approximately 70 miles in length along the Ohio River, between Powhattan Point and Marietta, Ohio. This map was used for locating new rail lines under the Pennsylvania Railroad System for development of industrial sites along the Ohio River. Quantities of excavation and costs were determined, both for the construction and property damage involved. An aerial mosaic was also prepared, using the same photos, which was a great aid in location and property damage determinations. The field control required consisted of 3rd order traverse along Ohio Route 7 which tied into existing U.S.G.S. monuments and monuments established by the Corps of Engineers. This traverse was run for the purpose of establishing individual photo control. As a result of these surveys and promotional work by the Railroad Company, a large industrial site is being developed and several other locations being considered. These maps and mosaics were furnished to the Railroad Company for less than $40,000.

Examples of recreational developments are Pymatuming State Park, Butler County Boy Scout Camp and Finlay State Park, Ohio. A topographic map showing 2-foot contours prepared by photogrammetric methods was used for location of camp sites and all phases of recreational development. The location of dams and capacities of proposed reservoirs can also be accurately determined from these same maps.

The next type of project which most civil engineers are interested in is large scale maps of subdivisions particularly around the large cities. The

complete subdivision can be layed out using an accurate topographic map prepared at any scale and contour interval desired. This map will serve as a base for location of streets, lot lines, drainage system, sanitary sewer system including treatment facilities, and furnish a reliable estimate for bidding purposes of all quantities involved for the construction of the project. An example of this is Dawson Ridge in Beaver County, Pennsylvania where more than 500 homes have been completed along with the shopping center to serve the general area.

Much work has been done by government agencies, and private companies under contract to government agencies, in preparing accurate maps for defense projects and on location and land use studies. These studies constitute planning for guided missels throughout the country, defense and commercial air bases and major irrigation projects in the western part of United States and foreign countries. These maps prepared for the government agencies vary in scale from 1:250,000 to 1:1,200.

A large scale mapping project is now underway by Army Map Service to provide complete coverage of the United States at 1:250,000 scale. These maps will provide complete coverage of areas not previously mapped and will be available for private industries as well as government agencies for the general planning of major projects including the proposed new Inter-State Highway System. In addition to the small scale maps being prepared by Army Map Service, U.S.G.S. is compiling up-to-date maps at a scale of 1:24,000 of most of the developed areas in the United States. This scale map will prove even more valuable to Civil Engineers.

Our Company recently completed a land use study and irrigation project designed using large scale photogrammetric maps and aerial mosaics of the Jordon River Valley. This work was performed under the International Cooperation Administration of the United States State Department, and was done for the purpose of providing productive land to make the people of Jordon self-supporting. This included the location of a proposed reservoir area along with all irrigation ditches and features to make the system operative. The program when completed will convert 150,000 acres into useable ground and cost approximately $150 million.

In the illustrations given above, I have attempted to show the many types of engineering projects in which photogrammetric maps have been the basis for planning and design. It is recognized that all major civil engineering projects must begin with an accurate and reliable map of the area involved, and I have further attempted to illustrate that photogrammetry has been developed and accepted as standard by all the U.S. Government Agencies and many State Highway Departments throughout the country. Since highway work comprises a large percentage of civil engineering work, within the next few years, it is reasonable to expect that photogrammetry will increase in volume and acceptance as a basis for study and design of all these projects.

PROCEEDINGS PAPERS

The technical papers published in the past year are identified by number below. Technical-division sponsorship is indicated by an abbreviation at the end of each Paper Number, the symbols referring to: Air Transport (AT), City Planning (CP), Construction (CO), Engineering Mechanics (EM), Highway (HW), Hydraulics (HY), Irrigation and Drainage (IR), Power (PO), Sanitary Engineering (SA), Soil Mechanics and Foundations (SM), Structural (ST), Surveying and Mapping (SU), and Waterways and Harbors (WW) divisions. Papers sponsored by the Board of Direction are identified by the symbols (BD). For titles and order coupons, refer to the appropriate issue of "Civil Engineering." Beginning with Volume 82 (January 1956) papers were published in Journals of the various Technical Divisions. To locate papers in the Journals, the symbols after the paper numbers are followed by a numeral designating the issue of a particular Journal in which the paper appeared. For example, Paper 861 is identified as 861 (SM1) which indicates that the paper is contained in issue 1 of the Journal of the Soil Mechanics and Foundations Division.

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DECEMBER: 842(SM), 843(SM)^c, 844(SU), 845(SU)^c, 846(SA), 847(SA), 848(SA)^c, 849(ST)^c, 850(ST), 851(ST), 852(ST), 853(ST), 854(CO), 855(CO), 856(CO)^c, 857(SU), 858(BD), 859(BD), 860(BD).

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JANUARY: 861(SM1), 862(SM1), 863(EM1), 864(SM1), 865(SM1), 866(SM1), 867(SM1), 868(HW1), 869(ST1), 870(EM1), 871(HW1), 872(HW1), 873(HW1), 874(HW1), 875(HW1), 876(EM1)^c, 877 (HW1)^c, 878(ST1)^c.

FEBRUARY: 879(CP1), 880(HY1), 881(HY1)^c, 882(HY1), 883(HY1), 884(IR1), 885(SA1), 886(CP1), 887(SA1), 888(SA1), 889(SA1). 890(SA1), 891(SA1), 892(SA1), 893(CP1), 894(CP1), 895(PO1) 896(PO1), 897(PO1), 898(PO1), 899(PO1), 900(PO1), 901(PO1), 902(AT1)^c, 903(IR1)^c, 904 (PO1)^c, 905(SA1)^c.

MARCH: 906(WW1), 907(WW1), 908(WW1), 909(WW1), 910(WW1), 911(WW1), 912(WW1), 913 (WW1)^c, 914(ST2), 915(ST2), 916(ST2), 917(ST2), 918(ST2), 919(ST2), 920(ST2), 921(SU1), 922(SU1), 923(SU1), 924(ST2)^c.

APRIL: 925(WW2), 926(WW2), 927(WW2), 928(SA2), 929(SA2), 930(SA2), 931(SA2), 932(SA2)^c, 933(SM2), 934(SM2), 935(WW2), 936(WW2), 937(WW2), 938(WW2), 939(WW2), 940(SM2), 941 (SM2), 942(SM2)^c, 943(EM2), 944(EM2), 945(EM2), 946(EM2)^c, 947(PO2), 948(PO2), 949(PO2), 950(PO2), 951(PO2), 952(PO2)^c, 953(HY2), 954(HY2), 955(HY2)^c, 956(HY2), 957(HY2), 958 (SA2), 959(PO2), 960(PO2).

MAY: 961(IR2), 962(IR2), 963(CP2), 964(CP2), 965(WW3), 966(WW3), 967(WW3), 968(WW3), 969 (WW3), 970(ST3), 971(ST3), 972(ST3)^c, 973(ST3), 974(ST3), 975(WW3), 976(WW3), 977(IR2), 978(AT2), 979(AT2), 980(AT2), 981(IR2), 982(IR2)^c, 983(HW2), 984(HW2), 985(HW2)^c, 986(ST3), 987(AT2), 988(CP2), 989(AT2).

JUNE: 990(PO3), 991(PO3), 992(PO3), 993(PO3), 994(PO3), 995(PO3), 996(PO3), 997(PO3), 998 (SA3), 999(SA3), 1000(SA3), 1001(SA3), 1002(SA3), 1003(SA3)^c, 1004(HY3), 1005(HY3), 1006 (HY3), 1007(HY3), 1008 (HY3), 1009 (HY3), 1010 (HY3)^c, 1011 (PO3)^c, 1012 (SA3), 1013 (SA3), 1014(SA3), 1015(HY3), 1016(SA3), 1017(PO3), 1018(PO3).

JULY: 1019(ST4), 1020(ST4), 1021(ST4), 1022(ST4), 1023 (ST4), 1024(ST4)^c, 1025(SM3), 1026 (SM3), 1027(SM3), 1028(SM3)^c, 1029(EM3), 1030(EM3), 1031(EM3), 1032(EM3), 1033(EM3)^c.

AUGUST: 1034(HY4), 1035(HY4), 1036(HY4), 1037(HY4), 1038(HY4), 1039(HY4), 1040(HY4), 1041(HY4)^c, 1042(PO4), 1043(PO4), 1044(PO4), 1045(PO4), 1046(PO4)^c, 1047(SA4), 1048 (SA4)^c, 1049(SA4), 1050(SA4), 1051(SA4), 1052(HY4), 1053(SA4).

SEPTEMBER: 1054(ST5), 1055(ST5), 1056(ST5), 1057(ST5), 1058(ST5), 1059(WW4), 1060(WW4), 1061(WW4), 1062(WW4), 1063(WW4), 1064(SU2), 1065(SU2), 1066(SU2)^c, 1067(ST5)^c, 1068 (WW4)^c, 1069(WW4).

OCTOBER: 1070(EM4), 1071(EM4), 1072(EM4), 1073(EM4), 1074(HW3), 1075(HW3), 1076(HW3), 1077(HY5), 1078(SA5), 1079(SM4), 1080(SM4), 1081(SM4), 1082(HY5), 1083(SA5), 1084(SA5), 1085(SA5), 1086(PO5), 1087(SA5), 1088(SA5), 1089(SA5), 1090(HW3), 1091(EM4)^c, 1092 (HY5)^c, 1093(HW3)^c, 1094(PO5)^c, 1095(SM4)^c.

NOVEMBER: 1096(ST6), 1097(ST6), 1098(ST6), 1099(ST6), 1100(ST6), 1101(ST6), 1102(IR3), 1103 (IR3), 1104(IR3), 1105(IR3), 1106(ST6), 1107(ST6), 1108(ST6), 1109(AT3), 1110(AT3)^c, 1111(IR3)^c, 1112(ST6)^c.

DECEMBER: 1113(HY6), 1114(HY6), 1115(SA6), 1116(SA6), 1117(SU3), 1118(SU3), 1119(WW5), 1120(WW5), 1121(WW5), 1122(WW5), 1123(WW5), 1124(WW5)^c, 1125(BD1)^c, 1126(SA6), 1127 (SA6), 1128(WW5), 1129(SA6)^c, 1130(PO6)^c, 1131(HY6)^c, 1132(PO6), 1133(PO6), 1134(PO6), 1135(BD1).

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c. Discussion of several papers, grouped by Divisions.

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